

Development of a strain-based flaw assessment methodology for pipeline welds

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I. INTRODUCTION

The immense global demand for energy puts a mortgage on Earth's fossil fuel reserves. Oil and gas suppliers progressively have to reach alternative sources, located in increasingly hostile environments, using transport pipelines. The occurrence of geological activity (e.g. seismic activity, permafrost) or installation difficulties (e.g. deep-water offshore) in those areas can subject the pipelines to plastic deformation.

Considering the integrity of a pipeline in such circumstances, the welds that connect the different pipe sections are critical. This is related to two main reasons: the inevitable presence of weld flaws, such as slag inclusions and porosities, and the possible deterioration of material properties in weld and heat-affected zone (HAZ).

In order to ensure pipeline integrity and thereby avoid ecological and economical disasters, the acceptability of all detected weld flaws should be assessed considering the environmental conditions. For pipelines located in the abovementioned hostile environments, this requires a displacement-based ('strain-based') approach, which can account for plastic deformations.

II. OBJECTIVE

Current flaw assessment standards are, without any exception, stress-based and have restricted possibilities in accounting for

imposed plastic strains. As a consequence, pipeline projects in harsh environments have so far been designed on a project-specific approach involving an extensive and costly experimental programme.

The objective of this PhD is to develop a more systematic, 'cookbook' strain-based flaw assessment methodology in an analytical way. The resulting procedure must be supported by experiments and numerical (finite-element) analyses, which can both be used as a design and/or as a validation tool.

III. SMALL-SCALE EXPERIMENTS

Small-scale experiments are used to reveal the material properties of the pipeline (base and weld metal). Here, focus is put on the two most important properties for pipeline integrity: stress-strain behaviour and ductile tearing behaviour.

A. *Stress-strain behaviour*

Since the stress-strain behaviour of the pipeline components obviously plays a major role, an extensive study of the post-yield tensile response of contemporary pipeline steels has been conducted. This led to the observation that the most common stress-strain model (Ramberg-Osgood), which is even advised in some pipeline standards, is inaccurate for a wide variety of high-strength pipeline steels. To deal with this limitation, a new 'UGent' stress-strain model has been developed, providing a clear improvement to the Ramberg-Osgood model [1]. Figure 1 shows an example stress-strain curve of a high-strength pipeline steel and curve-fits for both models, illustrating this improvement.

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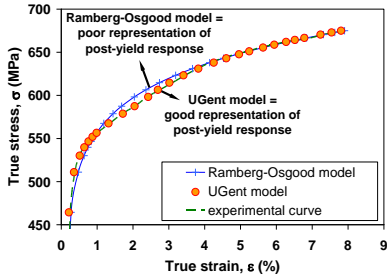


Figure 1: Model representations of a high-strength pipeline steel [1].

B. Ductile tearing behaviour

Ductile tearing is the stable growth of a crack through microvoid nucleation and coalescence. Today, no small-scale test is able to describe the tearing behaviour of defects in thin-walled pipelines. Hence, the development of such test will be attempted.

IV. NUMERICAL ANALYSES

A finite-element (ABAQUS®) model has been developed to investigate the influence of pipe and weld geometry, flaw geometry and position, and material properties. Application of a Python script enables parametric studies with a high level of automation [2]. Currently, the model (Figure 2) is able to evaluate the crack mouth opening and local stress-strain distribution for a randomly shaped weld with symmetric conditions (homogeneous pipe properties, flaw in centre of weld). In the future, a more advanced model will include ductile crack growth, pipe metal heterogeneity and flaws located in the HAZ.

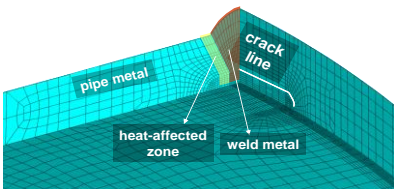


Figure 2: Detail of the developed finite-element model of a symmetrical weld [2].

V. ANALYTICAL PROCEDURE DEVELOPMENT

As mentioned above, the development of an analytical strain-based flaw assessment procedure is the main objective. To provide a degree of flexibility, the formulation of different analysis levels is desirable. This gives the user the opportunity to deliberately choose for a certain trade-off between complexity and conservativity.

The procedure will be based on the fundamental concepts of elastic-plastic fracture mechanics, containing its most relevant concepts: crack driving force, plastic collapse and crack tip constraint effects.

VI. CONCLUSIONS

This PhD project addresses the need for assessing pipeline weld integrity under plastic deformation, driven by the exhaustion of fossil fuel reserves. It will result in an increased knowledge of the structural response of pipelines to externally imposed plastic deformations, and a strain-based weld flaw assessment procedure that enables a systematic, fracture mechanics-based integrity check.

ACKNOWLEDGEMENTS

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